Geometry and Grid Generation Issues for MDO

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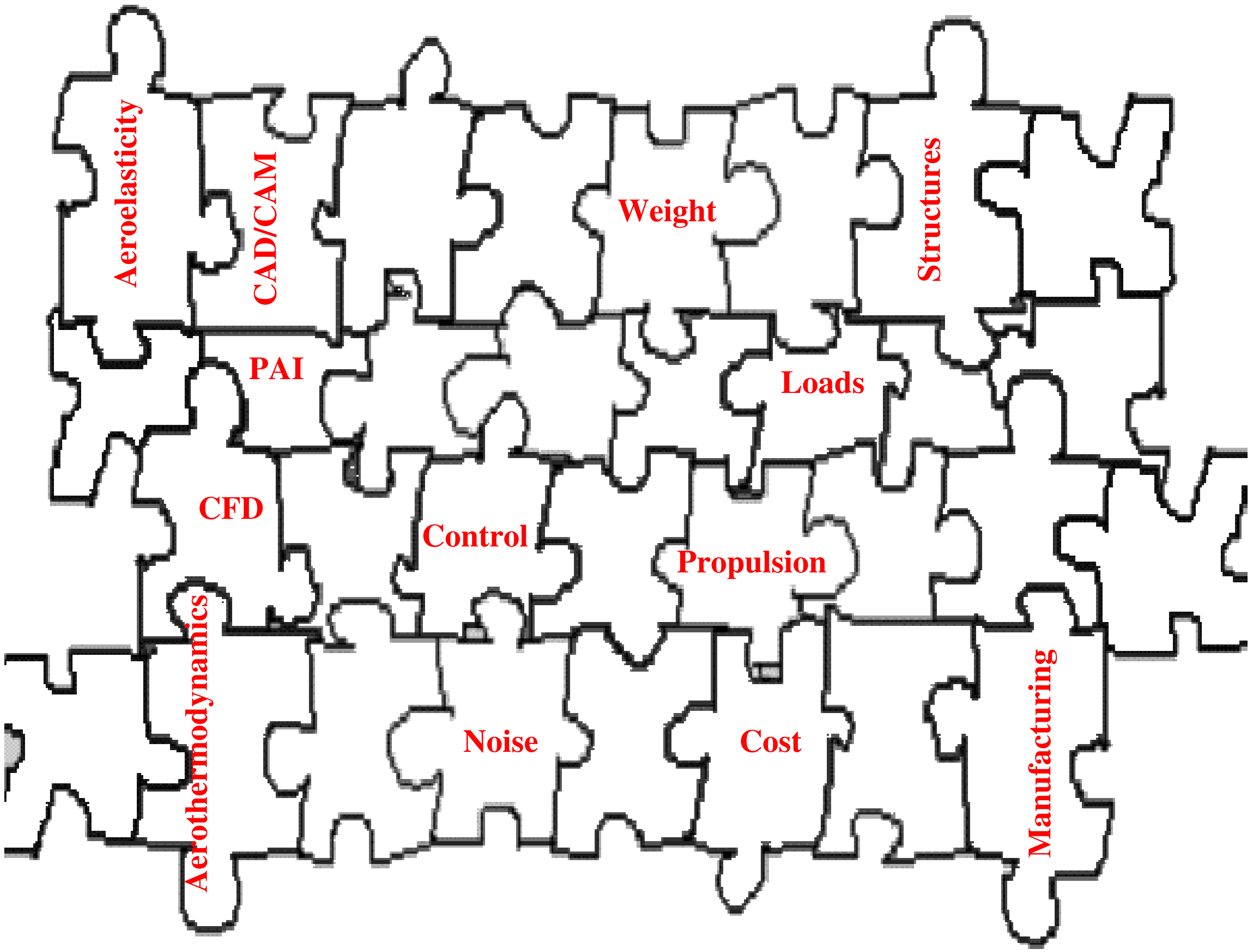
Slides are available from MDOB web site:

http://mdob.larc.nasa.gov/

Outline

- The case for high-fidelity MDO
- CAD-based shape optimization (long term goal)
- Shape deformation (short term solution)
- Issues & challenges

Aerospace Vehicle Design Puzzle



Aircraft Design Phases

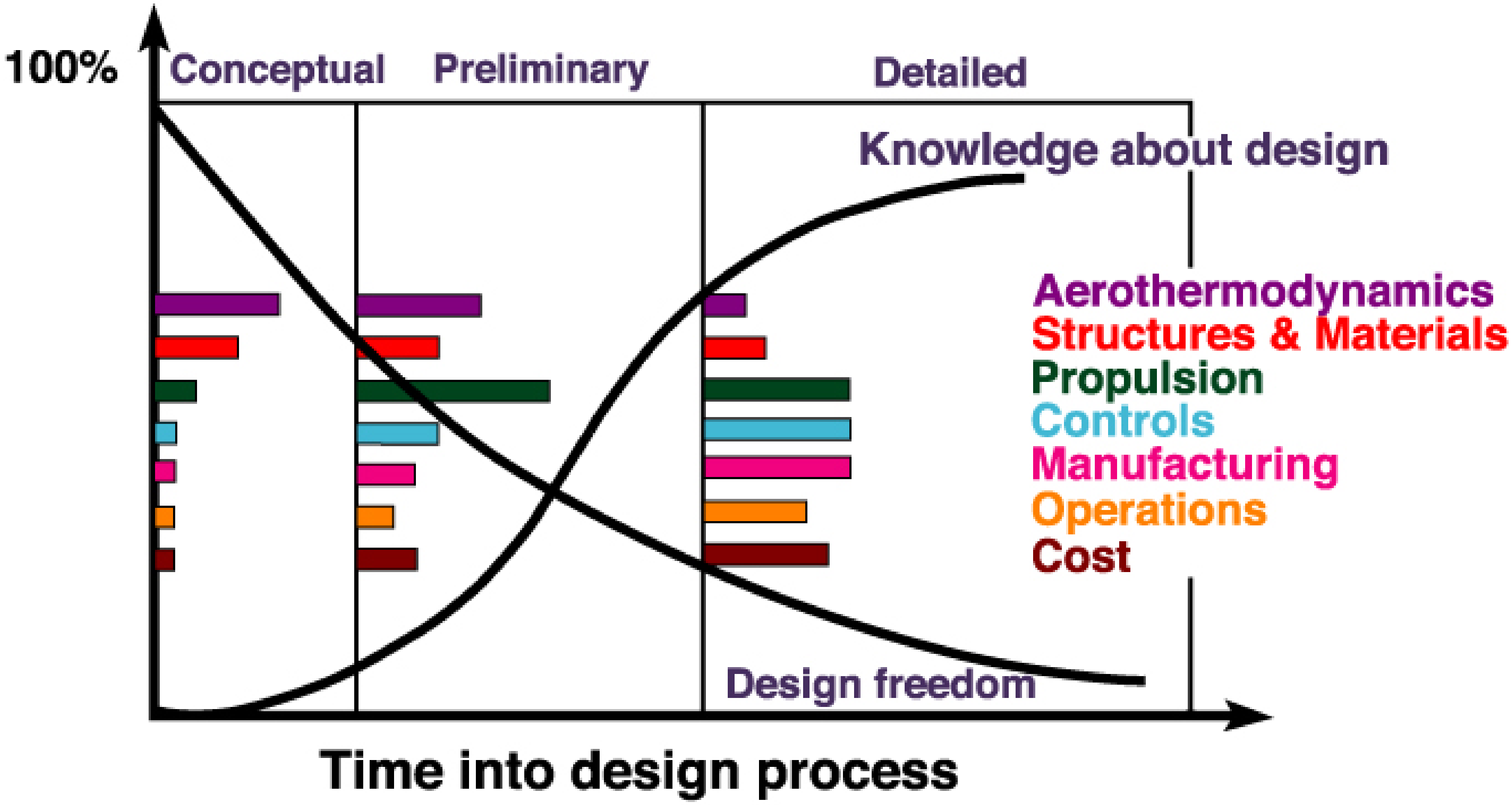
Design process can be broken into three phases*:

1. Conceptual design: basic design optimization of features, such as weights, sizes, and overall performance.
2. Preliminary design: mathematical modeling of the outside skin of an aircraft with sufficient accuracy. After this phase, the geometry is frozen, and any change could be costly.
3. Detail design: actual design of pieces to be fabricated.

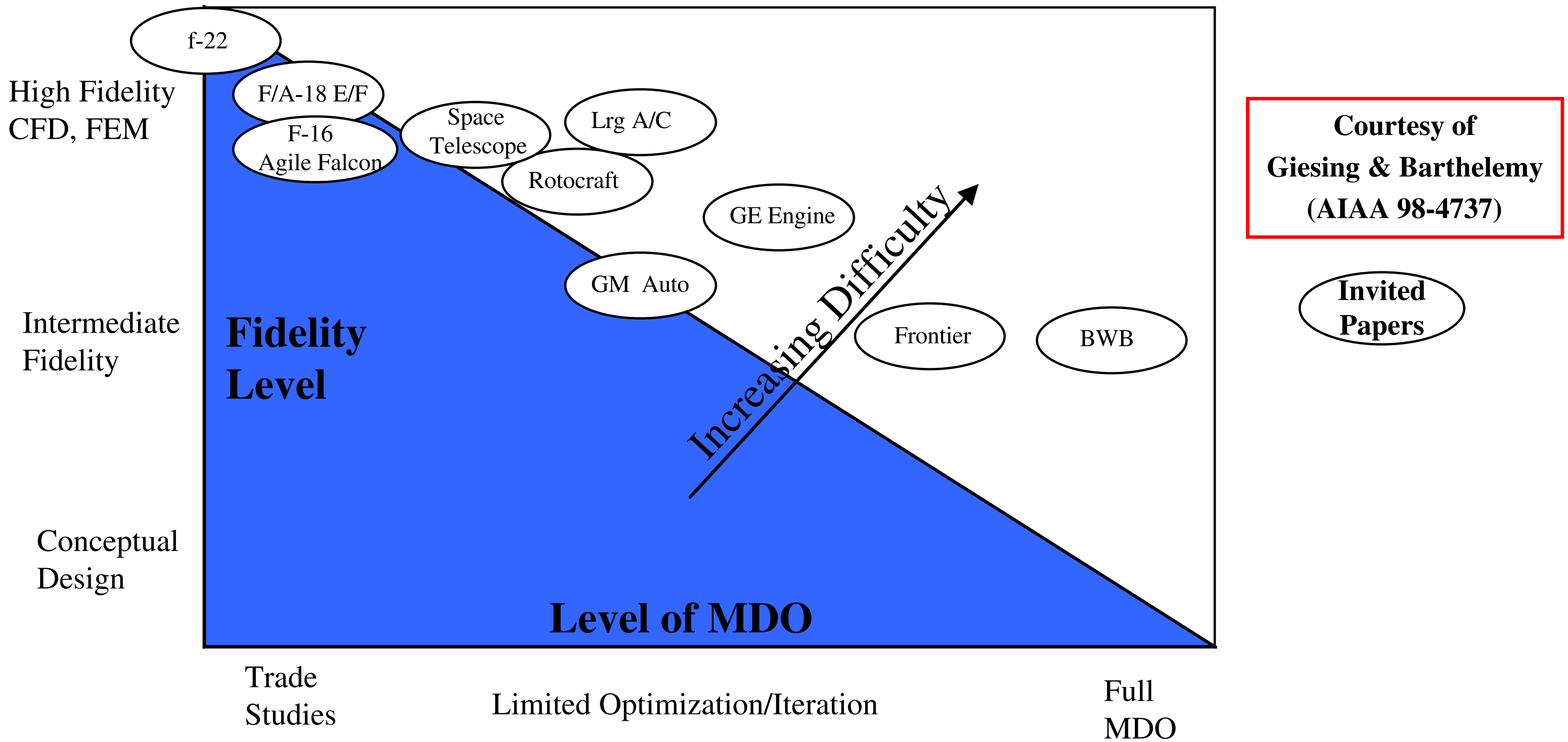
- *Raymer, D.P. " Aircraft Design: A Conceptual Approach,", 1989.

Traditional Aerospace Design Practice

Uneven Distribution of Knowledge & Efforts



Summary of 10 invited papers on industrial experience with MDO (MA&O Conference 1998)



"High fidelity analysis process is difficult or impossible to include in MDO"

("Non Automated", "Very long computing time")

Are geometry modeling and grid generation tools ready to be integrated into a high-fidelity multidisciplinary design and optimization environment for complex models?

Observations 1

High-fidelity geometry model:

1. contains <u>thousands</u> of parts
2. many parts are not necessarily suitable directly for analysis —days or weeks of <u>massaging</u> are needed
3. may differ from the actual vehicle in significant respects — this inherent variability leads to uncertainty in how well the analysis results predict the actual vehicle

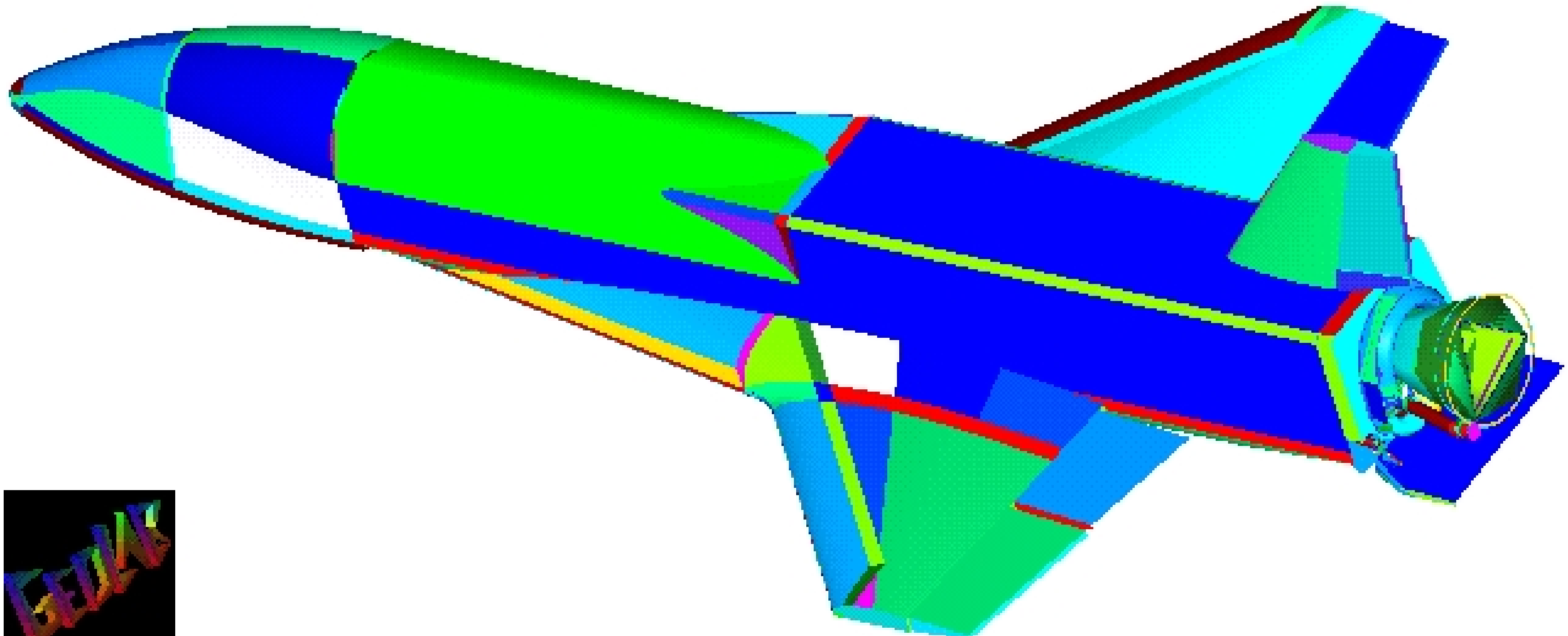
Observations 2

Each discipline:

1. requires <u>different geometry models</u>
2. may contain <u>different vehicle components</u>
3. may not have coincident surfaces
4. has its own requirements for smoothness
5. may deform the geometry (need link back to CAD)
6. may require analytical sensitivity analysis which could be a major barrier for using CAD models directly in optimization

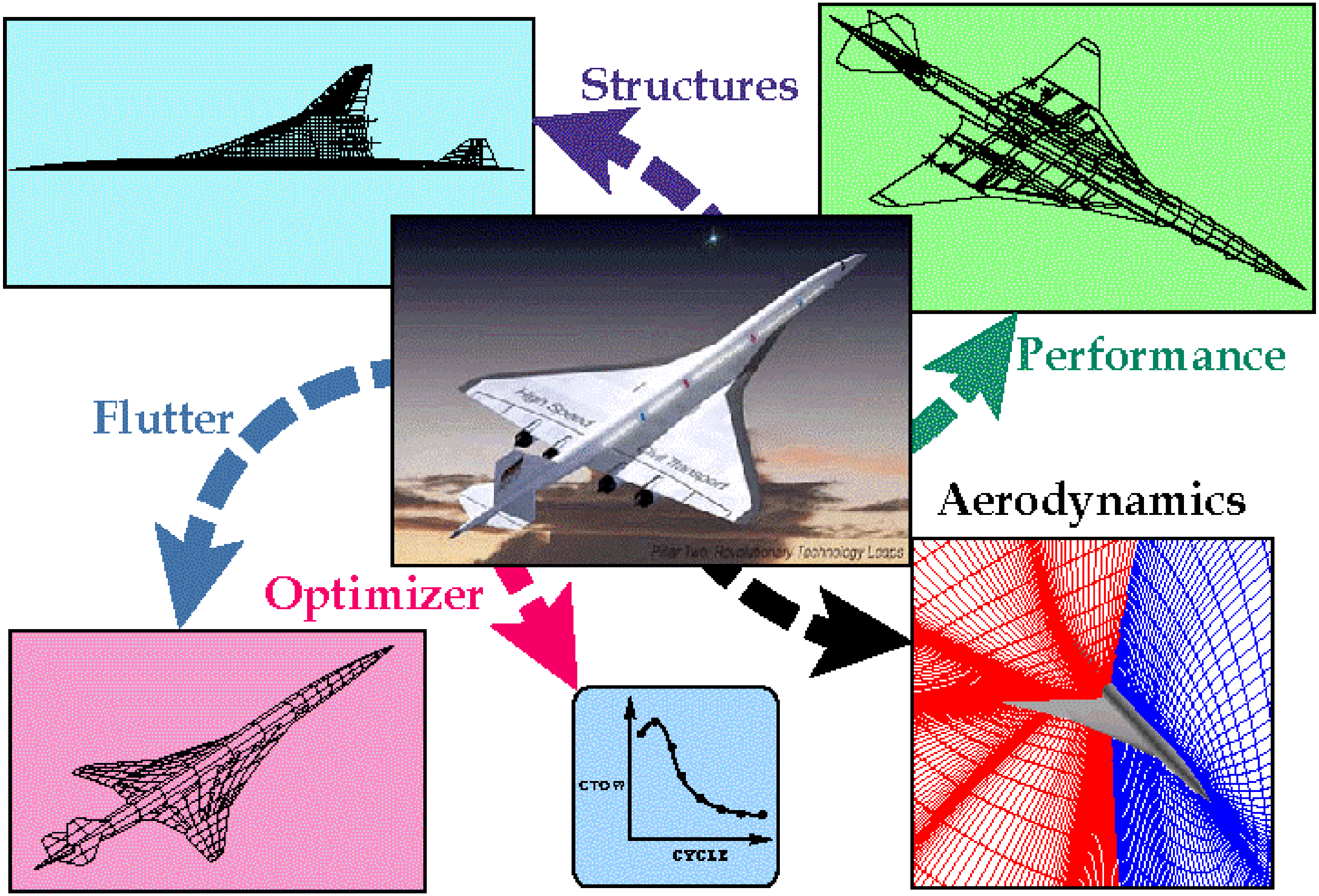
Preliminary Design Geometry

X34 CAD Model

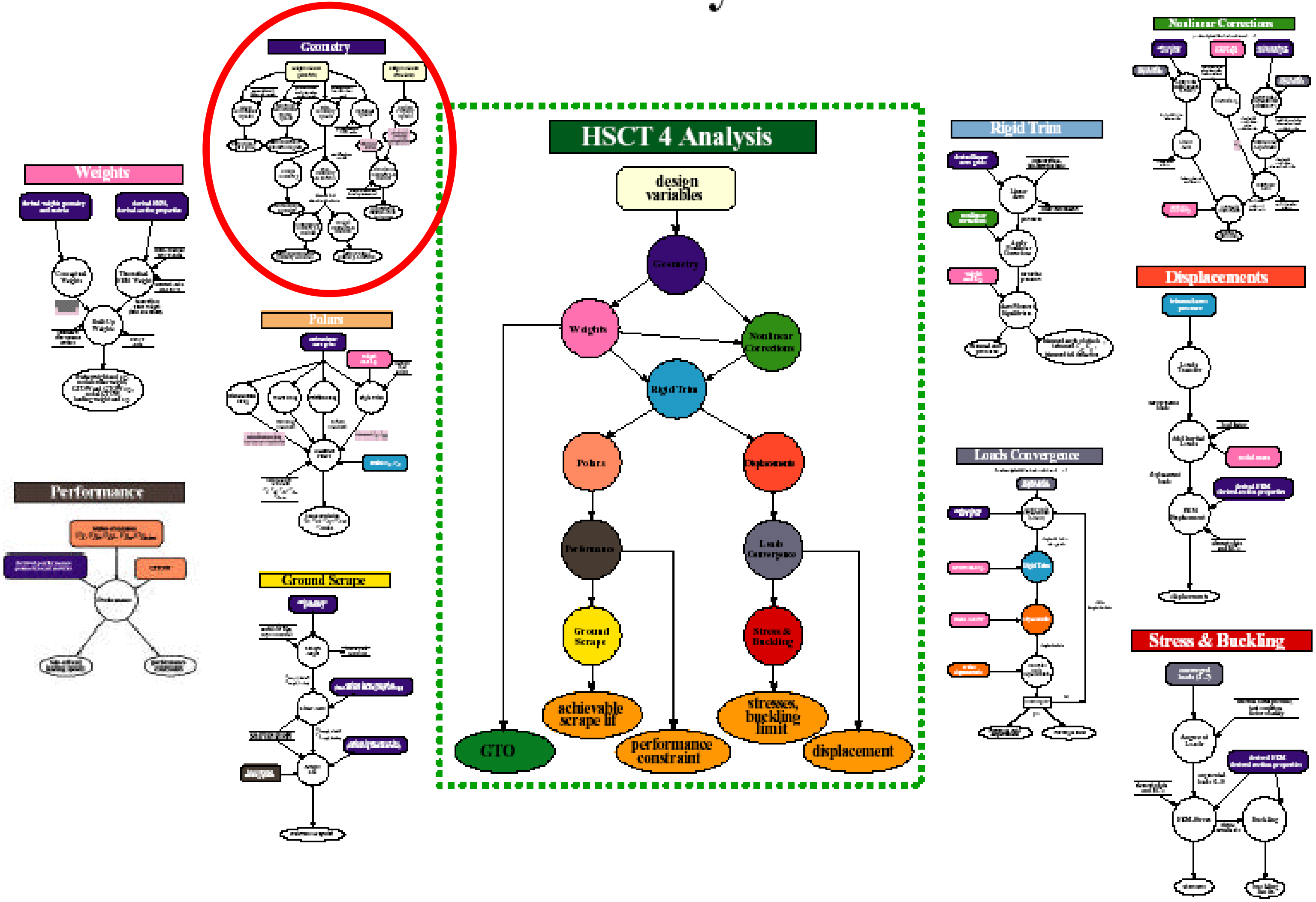


23,555 curves and surfaces

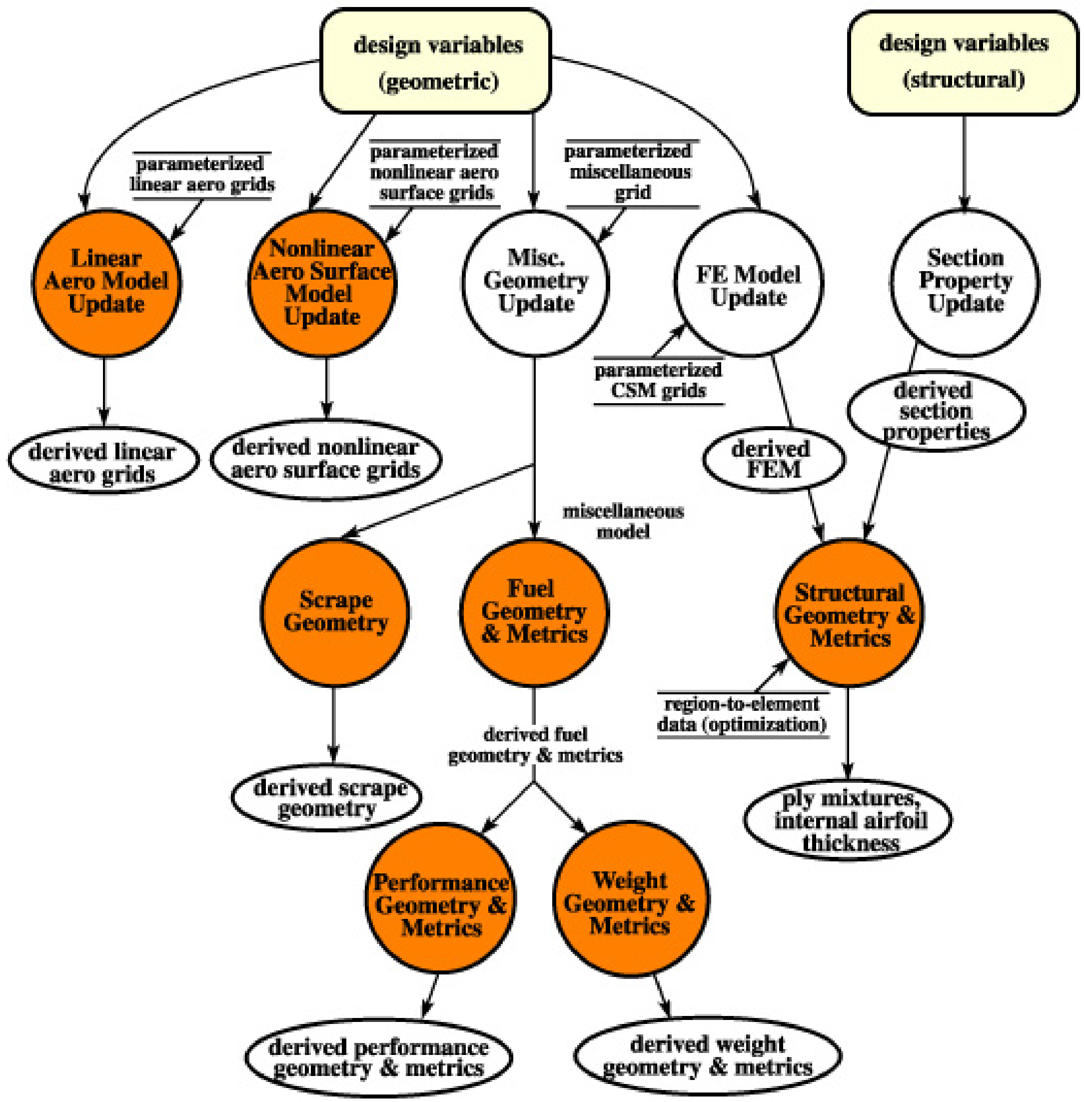
High-Fidelity MDO of an Aerospace Vehicle



Full HSCT 4 Analysis Procedures



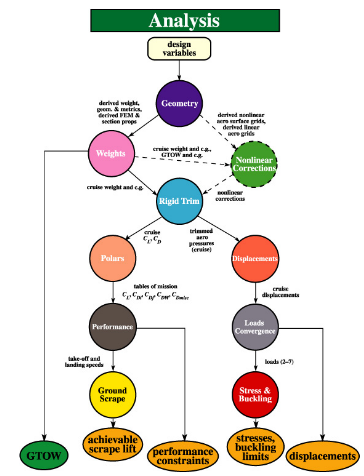
Geometry

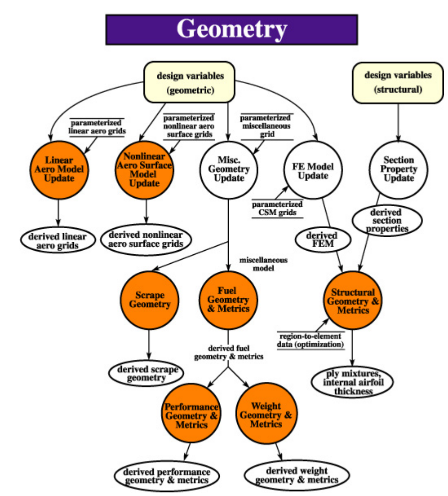


design variables (geometric)
design variables (structural)
parameterized linear aero grids
parameterized nonlinear aero surface grids
parameterized miscellaneous grid
Linear Aero Model Update
Nonlinear Aero Surface Model Update
Misc. Geometry Update
FE Model Update
Section Property Update
parameterized CSM grids
derived linear aero grids
derived nonlinear aero surface grids
derived FEM
derived section properties
miscellaneous model
Scrape Geometry
Fuel Geometry & Metrics
Structural Geometry & Metrics
region-to-element data (optimization)
derived fuel geometry & metrics
derived scrape geometry
ply mixtures, internal airfoil thickness
Performance Geometry & Metrics
Weight Geometry & Metrics
derived performance geometry & metrics
derived weight geometry & metrics

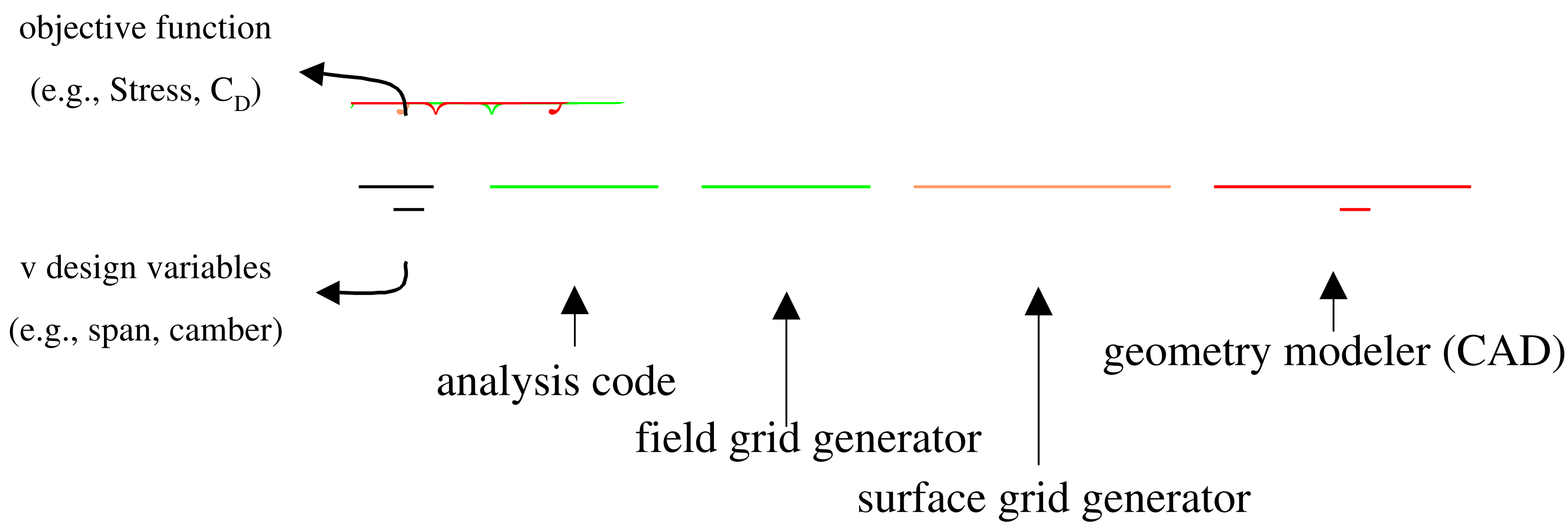
Geometry Modeling Issues for HSCT4

- **Existing non-parametric CAD and FE models**
- **Geometry model needs to be parametric**
- **7 different processes need geometry models**
  - Linear aerodynamics (USSAERO)
  - Nonlinear aerodynamics (CFL3D)
  - Finite-element structural analysis (GENESIS)
  - Fuel
  - Weights
  - Performance (FLOPS)
  - Ground Scrape
- **Aero and structural models have different grids**
- **Vehicle deflects under loads**
- **Sensitivity derivatives are needed for optimization**



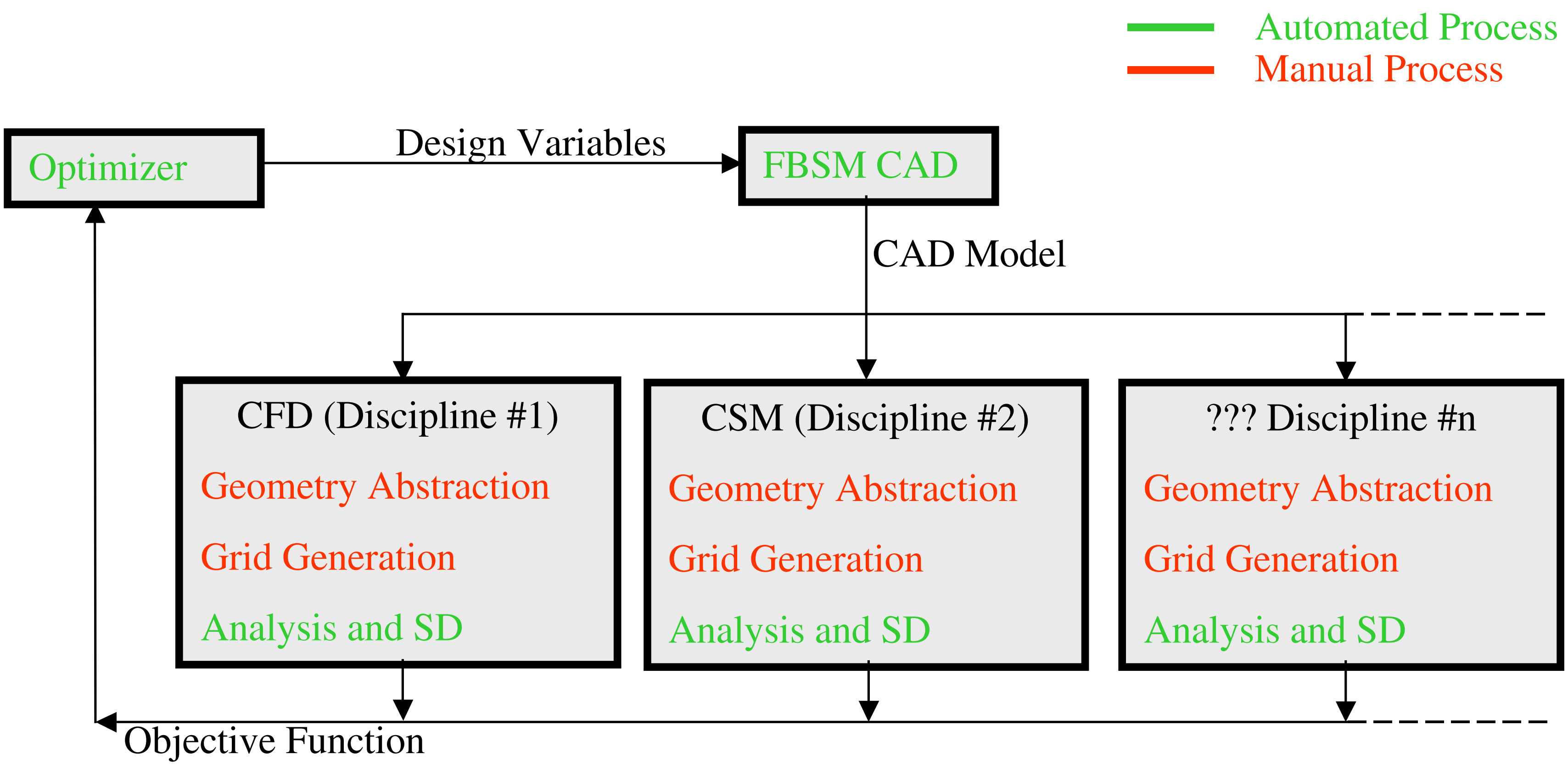


Sensitivity Analysis



- Manual differentiation
- Automatic differentiation tools (e.g., ADIFOR and ADIC)
- Complex variables
- Finite-difference approximations (may not be possible for CAD)

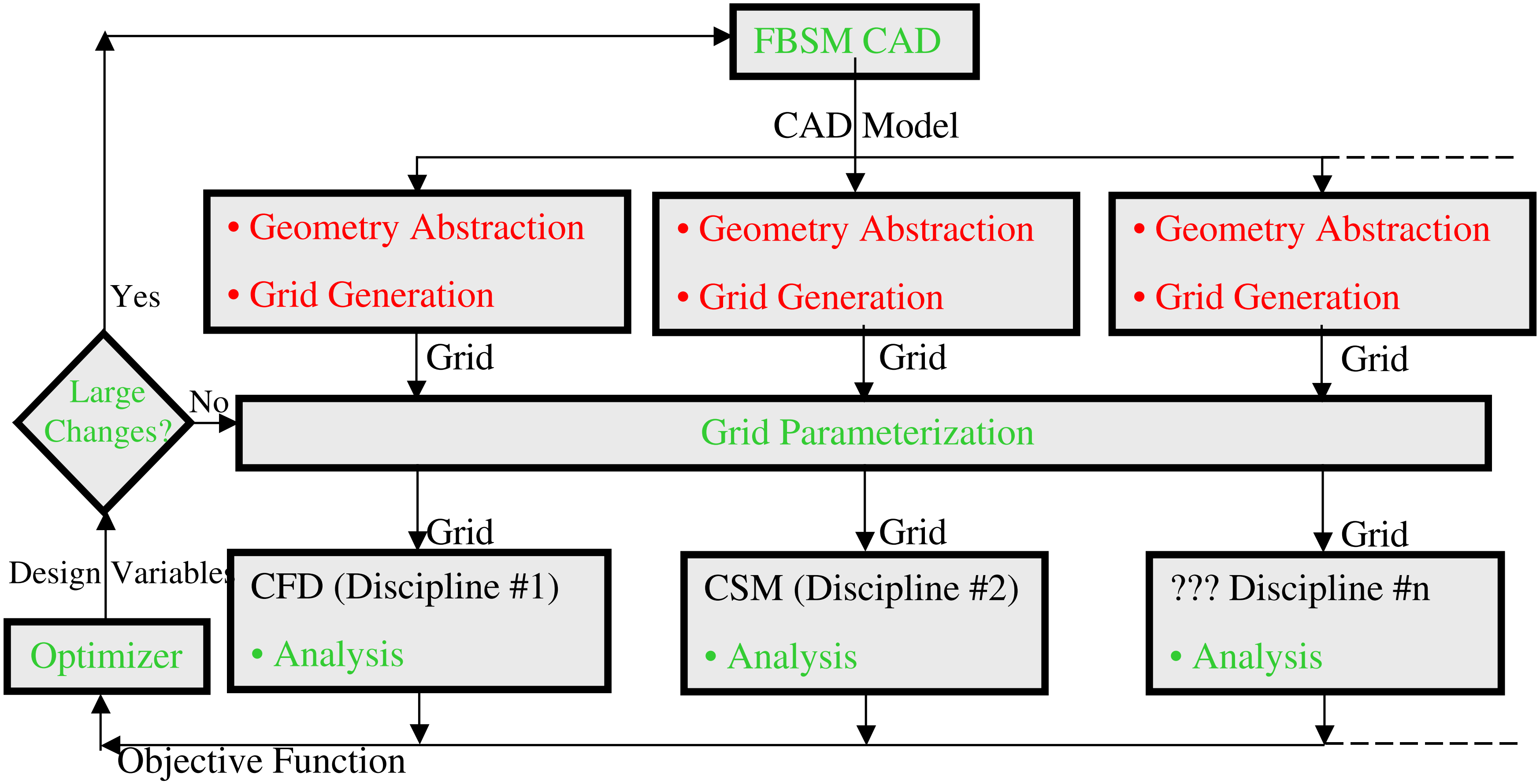
Long Term CAD-Based MDO Goal (Current Status)



CAD-Based MDO
(Current Status)

- **Consistent**: Will the process be consistent across multiple disciplines? (Yes)
- **Automatic**: Can geometry abstraction be automated? (No)
- **Grid generation**: Can we generate grids automatically based on a CAD model for all disciplines? (No)
- **Setup time**: How quickly can it be set up? (Days)
- **Compact**: Will it provide a compact set of design variables? 10s vs. 1000s (Yes)
- **Analytical Sensitivity**: Is it feasible to calculate sensitivity data analytically? (No)

Automated High-Fidelity MDO
(Short Term Solution)

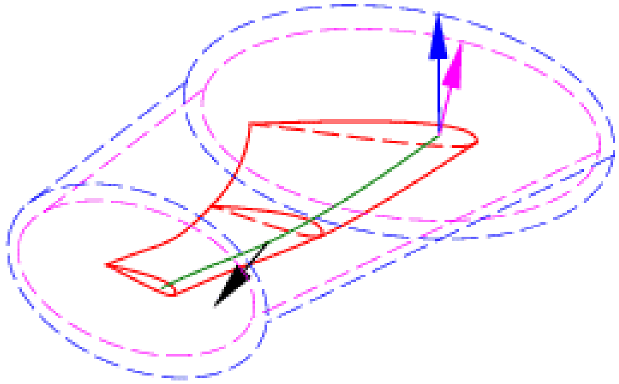


Multidisciplinary Aerodynamic-Structural Shape Optimization Using Deformation (MASSOUD)

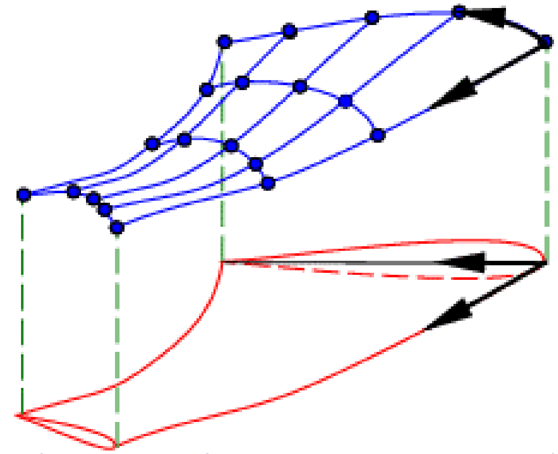
(Samareh, J., "Novel Multidisciplinary Shape Parameterization Approach," Journal of Aircraft, Vol. 38, No. 6, November-December 2001)

- Parameterizes the changes in shape, not the shape itself (reduces the number of design variables)
- Parameterizes the discipline grids (avoids manual grid regeneration)
- Uses advanced soft object animation algorithms for deforming grids
  - NURBS surface (camber and thickness)
  - Free-form deformation (planform)
  - Nonlinear global deformation (twist and dihedral)

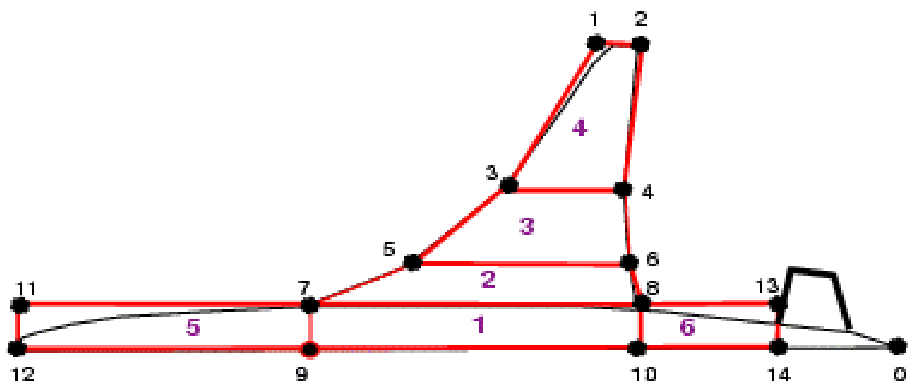
Multidisciplinary Aero/Struc Shape Optimization Using Deformation (MASSOUD)



Nonlinear global deformation
(Twist and Dihedral)



Deformation of parametric NURBS surfaces
(Camber and Thickness)

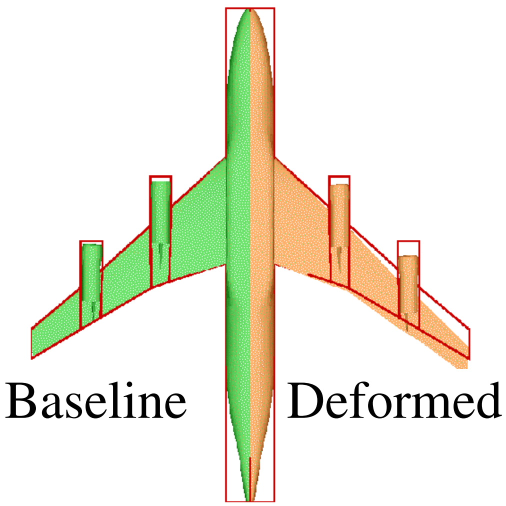


Free–form deformation
(Planform)

MASSOUD (Cont.)

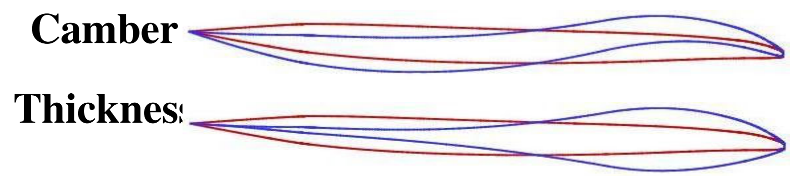
Planform Parameterization

(CFD surface grid of a generic transport)



Camber/Thickness Parameterization

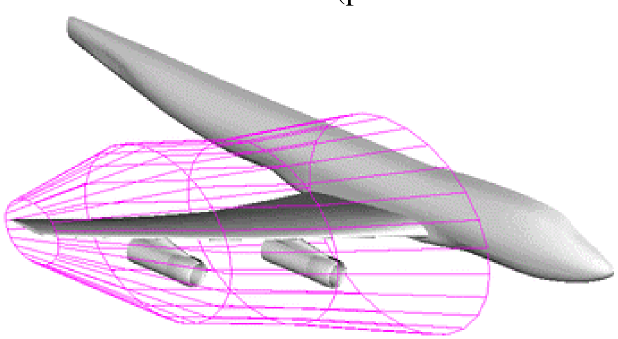
(Airfoil)

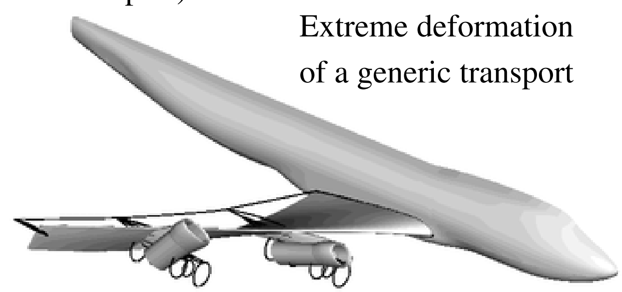


Extreme camber & thickness deformation

Twist/Dihedral Parameterization

(parameterization of a generic transport)

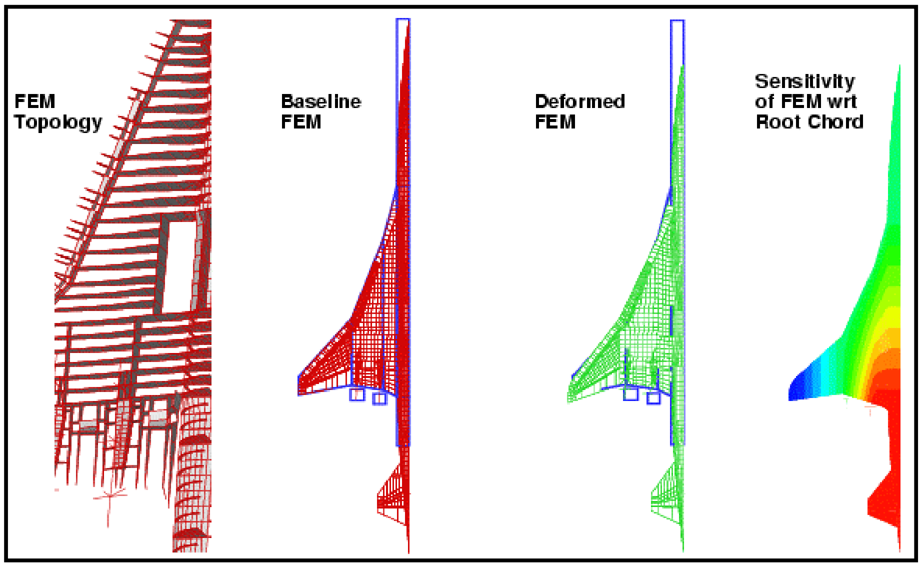




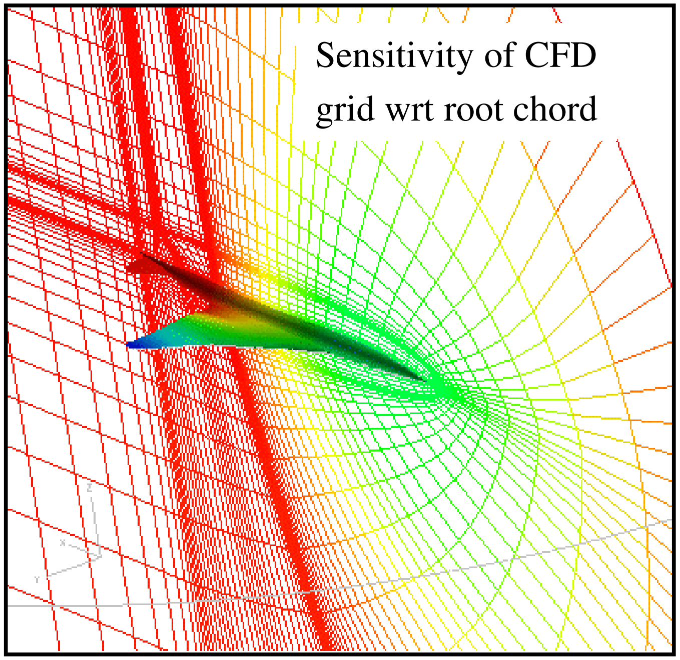
Extreme deformation of a generic transport

Multidisciplinary Shape Parameterization of an HSCT Model (HSCT4)

- Automated process
- 27 aerodynamic shape design variables
- Analytical sensitivity



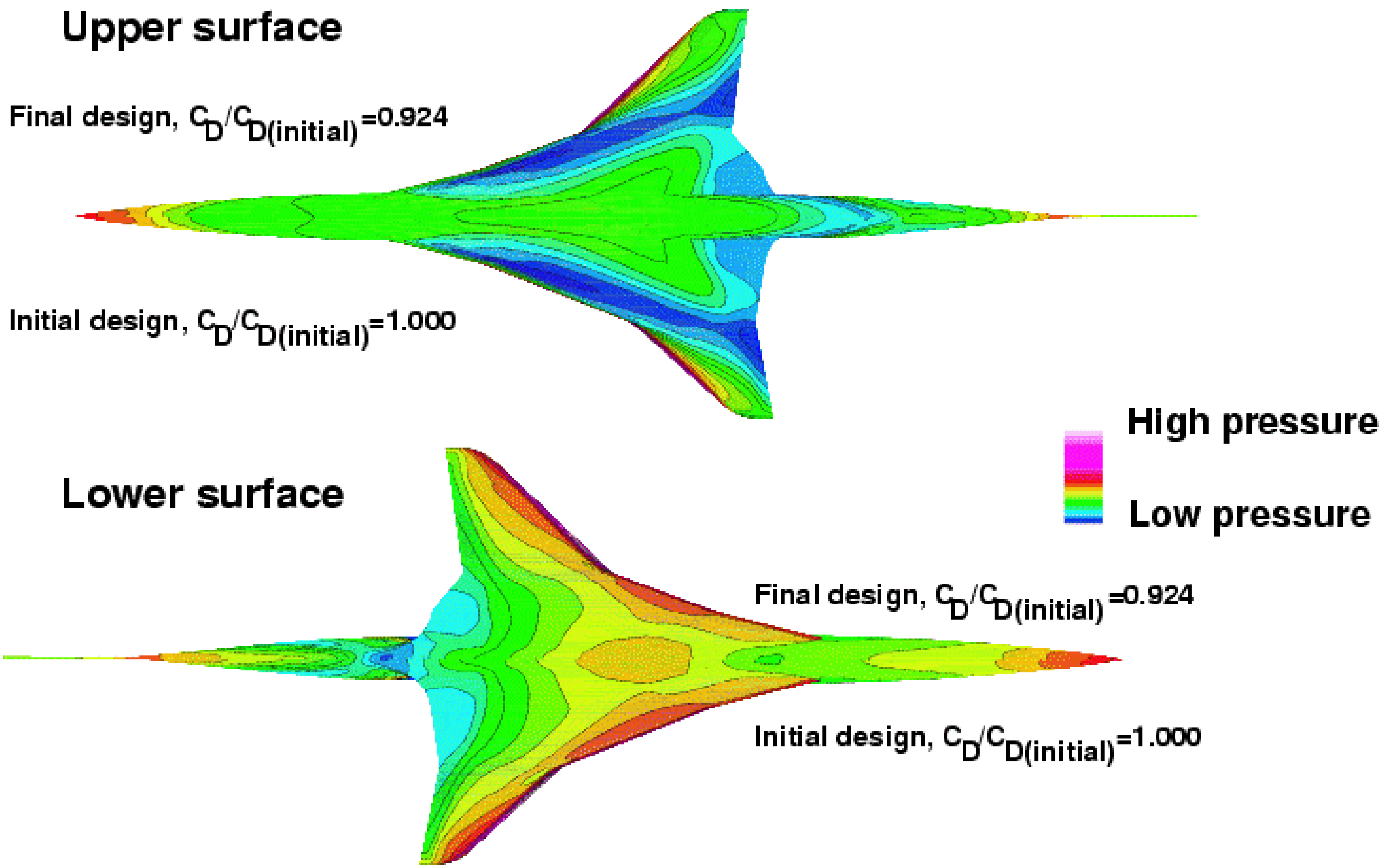
FE Model



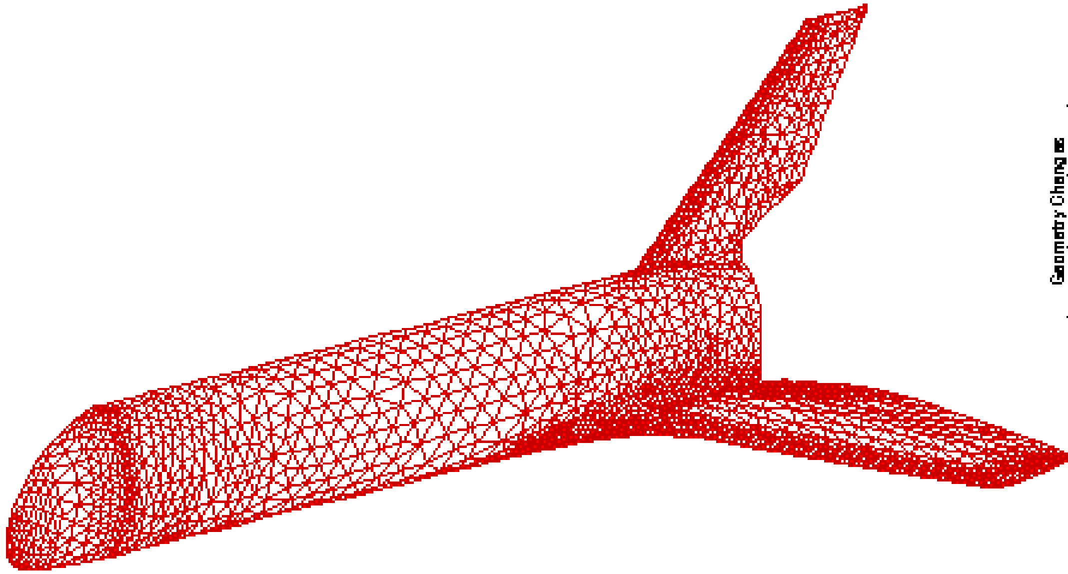
CFD Model

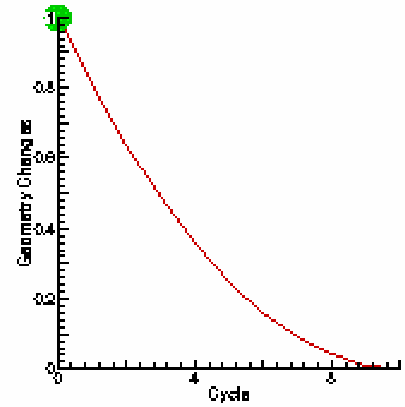
Nonlinear Aerodynamic Shape Optimization Results

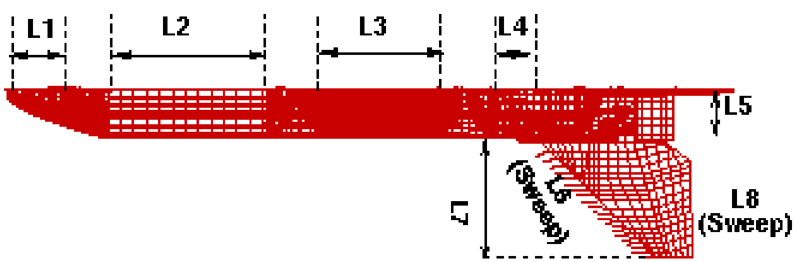
Final design $C_D/C_{D(initial)}$=0.924, Fixed C_L

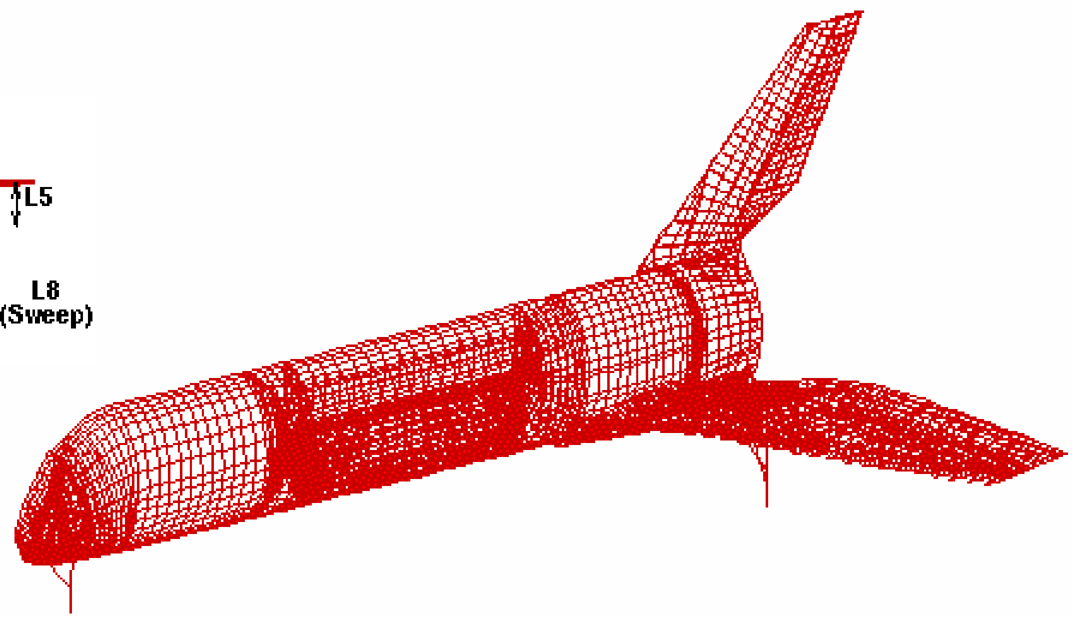


Launch Vehicle Shape Parameterization









MASSOUD's Pros & Cons

✓ Pros

- Is consistent
- No need for grid generation
- Easy to setup (hours)
- Parameterization is fast (seconds on OCTANE)
- Analytical sensitivity is available
- Has compact set of DVs
- Suitable for high- and low-fidelity applications

Cons

- Limited to small shape changes
- Fixed topology
- No built-in geometry constraints
- No direct CAD connection

Model Abstraction

- CSM model design and abstraction
  - Dimensional reduction (solid to beams and/or shells)
- Deletion and/or suppression of small features (e.g., bolt holes)
- Modification (e.g., closing trailing edge)
- Addition (e.g., surface boundaries for gridding)
- Combination and/or split geometry parts (e.g., creating bigger surfaces for gridding)

Grid Generation

- Sensitivity analysis should be incorporated into grid generation tools
- Structured grids with fixed topology are only suitable for MDO applications with small geometry changes
- Structured grids can not be incorporated into MDO applications with moderate to high geometry changes without automatic topology creation
- Unstructured and Cartesian grids are well suited for MDO applications

Issues and Challenges

"Design automation tools will thrive in the next decade" *CAD Report, January 2000*

- Automation of geometry abstraction
- Grid generation:
  - Automation of grid generation tools: (use of GUI should be limited to problem set up and monitoring phases)
  - Sensitivity analysis should be built into the grid generation tools
  - Grid generation tools must be robust (eliminating rework)
- CAD-based sensitivity analysis (preferably analytical)

References

- Samareh, Jamshid A., "Survey of Shape Parameterization Techniques for High-Fidelity Multidisciplinary Shape Optimization," AIAA Journal, May 2001, pp. 877-884.

- Samareh, J., “Novel Multidisciplinary Shape Parameterization Approach,” Journal of Aircraft, Vol. 38, No. 6, November-December 2001, pp. 1015-1024.

- Jamshid A. Samareh: "Multidisciplinary Aerodynamic-Structural Shape optimization Using Deformation", AIAA Paper No. 2000-4911 LTRS.

- Samareh, J. A.: "Status and Future of Geometry Modeling and Grid Generation for Design and Optimization,“ J. Aircraft, Vol. 36, No. 1, Jan.-Feb. 1999, pp.97-104.